91602
new 82-10

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if
Reproduced in Whole or in Part

ontario hydro
research division

To: Dr. D. Mills
Director of Research

SURFWEAR-EXPERT SYSTEM FOR ENGINEERING OF WEAR RESISTANT SURFACES AND FOR WEAR PROBLEM DIAGNOSIS

P. Mayer and D. LeFrancois

SURFWEAR expert system package was developed for use by designers and maintenance personnel who are involved in surface engineering. It is intended to assist their efforts in identifying proper methods for improving wear resistance of metal surfaces. By asking simple questions the program guides the user to those processes which will likely provide the best results.

For the first time, decades of accumulated knowledge, expertise and experience of tribologists, engineers, and technicians are available in microcomputer accessible form. In a matter of seconds one can determine an applicable process, to improve wear resistance. A thorough metallurgical analysis should be performed during the failure investigation. SURFWEAR is based on reliable information published in the public domain and accepted by the practising experts in the area of surface engineering for wear resistance.

The SURFWEAR expert system package is designed for ease of use, and no previous computer experience or computer programming knowledge is required.

1. INTRODUCTION

Surface engineering is a discipline aimed at tailoring the properties of the surfaces of materials in such a way as to improve their function or serviceability. The demand for longer life of metallic structures and products under increasingly severe service conditions, the realization of replacement costs, and the recognition of the importance of conserving metallic resources all emphasize the need for wear resistance.

Determining (or anticipating) the wear mode is important for the prevention of future problems. The root cause of damage can be established and proper ameliorative measures taken only when the wear mode is identified correctly. The correct identification of the wear mode, and a solution to the wear problem, is a complex process which may include many individuals and institutions.

job	file	date	report no
84-505-051	827.0	January 8, 1991	90-265-K

91-07182/

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

Technical specialists in metallurgy and chemistry rely on personal experience and large amounts of reports, theories, studies, private communications and investigations concerning the different wear modes and methods of dealing with them.

As a result of many years of serious effort, information exists which makes possible correct identification of common wear modes and solutions to reduce/eliminate their effects. Expert systems, also known as knowledge-based systems, appear to be an effective tool for transferring this knowledge gained through research and field experience to individuals responsible for choosing surface treatments. Expert systems are computer programs that use knowledge and inference procedures to mimic the deductive reasoning used by human experts. An expert system is a form of artificial intelligence which can be used for diagnosis, monitoring, analyzing, consulting, designing, and many other applications.

This report begins by discussing the basic categories of wear, and wear modes, then it moves on to describe expert systems in general which leads to a discussion of the SURFWEAR expert system package. Finally, an example of an interactive session with SURFWEAR is presented and concluding remarks are given.

2. CATEGORIES OF WEAR AND WEAR MODES

Wear is damage to a solid surface, usually involving progressive loss of material, due to relative motion between that surface and a contacting substance or substances. Four basic categories of wear were considered: abrasion, erosion, adhesion, surface fatigue. These represent all common wear occurrences.

The four basic categories of wear have been further categorized into 17 basic wear modes which can independently or jointly cause damage to surfaces.

- Abrasion:
  - Low stress
  - High stress
  - Gouging
  - Polishing
- Erosion:
  - Solid impingement
  - Fluid impingement
  - Cavitation
  - Slurry erosion
- Surface fatigue:
  - Pitting
  - Spalling
  - Impact
  - Brinelling
- Adhesion:
  - Fretting
  - Adhesive
  - Seizure
  - Galling
  - Oxidative wear

A wear mode is defined as the process which degrades the surface of a component. Determining the correct wear mode is critical for the prevention of future damage. Proper corrective measures can be undertaken to alleviate the root cause or causes for surface damage only when the correct wear mode is known.

3. EXPERT SYSTEMS

3.1 General Description

An expert system is a type of artificial intelligence program that emulates the interaction a user might have with a human expert on a subject area. Expert systems can be developed for any problem that involves a selection from among a definable group of choices where the decision is based on logical rules. The rules can involve relative probabilities of a choice being correct. Any area where there is a person or group of persons that have special expertise needed by others is a possible area for expert systems. Anything from identification of biological specimens, to automating complex regulations, to aiding customers in selecting from among a group of products, to automated user assistance is possible.

Expert systems deal with knowledge rather than data and the files they use are often referred to as knowledge bases. The rules that the program uses are IF-THEN type rules. A rule is made up of a list of IF conditions (normal English sentences) and a list of THEN conditions (more sentences) or statements about the probability of a particular choice being the appropriate solution to the problem. The computer determines what additional information it needs and how best to get this information. If possible, the program will derive information from other rules rather than asking the user. This ability to derive information allows the program to combine many small pieces of knowledge to arrive at logical conclusions about complex problems.

The final goal of an expert system is to select the most appropriate solution to a problem based on the data input by the user. If more than one solution is possible, the program could provide a list of the possible solutions arranged in order of probability.

3.2 Benefits and Risks

Expert systems offer the following benefits:

- The knowledge about a limited domain is captured in the detail required for machine logic processing; a good knowledge representation will identify areas where the knowledge is uncertain or incomplete; areas for further research become clearly defined and the experiments to be performed are readily apparent (sharpening the expert).

- Human experts can be distracted or rushed and led to incorrect or inconsistent deductions; the expert system will always apply the same logic and give consistent results; the results will be correct if the rules are; when the expert system cannot arrive at a conclusion, it refers the user to the human expert (best knowledge base always gives best conclusion).

- All conclusions reached by the expert system are justified by inspectable rules; the human expert is freed from remembering all the details of the justification: this is a great time saver in areas where justification is repeatedly requested for slightly different inputs; in cases of disagreement among experts, the knowledge base challenges other experts to point out errors or to generate a correct rulebase (public thinking tool).

- With appropriate help facilities, an expert system can become an excellent tutor for transferring knowledge from an expert to his successor; this provides a company with some measure of protection against loss of expertise through attrition (preservation of knowledge).

- Non-specialists have access to expert knowledge if the expert is not available; problems that are well understood can be solved by anyone who has access to the expert system, this frees the expert from repeatedly executing the same task so that he can concentrate his efforts on acquiring new knowledge (efficient use of manpower.)

The risks involved in expert systems are the same as those associated with any computer program. The conclusions arrived at by an expert system may be wrong if the rules are incorrectly written and/or when the data entered by the user is wrong. Although SURFWEAR is designed to guard against misinterpretation, conclusions should be treated like any conclusions of a single expert. A second opinion is recommended if an incorrect conclusion entails great risks.

3.3 The Expert System Shell Used

A program used to build an expert system is usually called an *expert system shell*. EXSYS[1], one of the many shells available, was used to create the expert system described in this report. EXSYS is a generalized expert system development package. Expert systems can be developed with EXSYS for any problem that involves a selection from among a definable group of choices where the decision is based on logical rules. The rules can involve relative probabilities of a choice being correct.

Expert systems developed with EXSYS will ask the user questions relevant to a subject. The user answers by selecting one or more answers from a list by entering a numeric value. The computer will continue to ask questions until it has reached a conclusion. The conclusion may be the selection of a single solution or a list of possible solutions arranged in order of likelihood. The computer can explain, in English, how it arrived at its conclusion and why.

Expert system shells, such as EXSYS, coupled with the advance in micro-computer technology means that expert systems can be effectively built, installed on personal computers, and used by all who may need the assistance at low costs.

4. SURFWEAR EXPERT SYSTEM PACKAGE - DIAGNOSIS OF WEAR PROBLEMS AND RECOMMENDATIONS FOR WEAR RESISTANT SURFACES

The SURFWEAR expert system package was developed for use by designers and maintenance personnel who are involved in surface engineering. It is intended to assist their efforts to recognize and identify a basic wear mode that can produce surface damage, as well as recommend an applicable method to improve wear resistance. The program guides the user to the most likely wear mode by asking simple questions about the operating environment. Once the wear mode is determined the program then narrows down applicable processes by asking what type of metal the substrate is made of.

The acceptance of an expert system depends on the credibility of its knowledge base. In the conceptual design of SURFWEAR, two criteria were established for selecting the main source for the factual portion of the knowledge base. The facts should have been: (i) published in public domain so that their reliability could be judged; and (ii) accepted by the practising experts in the area of wear analysis and surface engineering.

The book, "Surface Engineering For Wear Resistance" [2] met both criteria and was chosen to be the factual framework for SURFWEAR.

The SURFWEAR knowledge base was constructed around the 17 basic wear modes described in Section 2. This knowledge is organized into a decision tree structure incorporating the facts from the source book, Surface Engineering for Wear Resistance, and heuristic components contributed by the developers of SURFWEAR. The facts are expressed in the form of production rules using the EXSYS expert system development package.

Expert systems developed with EXSYS, such as SURFWEAR, can be run on any IBM PC, XT, AT or compatible computer which has at least 256 K of RAM, one single sided disk drive, and uses DOS Version 2.0 or higher. An easy to follow User's Guide accompanies the software and gives more details regarding system requirements. The guide describes, and explains how to use, all the features of SURFWEAR (running, printing, displaying graphics, etc). The SURFWEAR User's Guide can also be used as a reference and/or learning tool since it includes descriptions of all the wear modes and surface improvement processes used in the program. This User's Guide together with the floppy disks make up the SURFWEAR expert system package.

Use of this expert system package does not eliminate the need for a thorough metallurgical analysis during a failure investigation since such an analysis is essential in many cases to confirm or ascertain the responsible damage mechanisms.

5. EXAMPLE OF AN INTERACTIVE SESSION

For the purpose of demonstrating an interactive session with the SURFWEAR expert system, assume that we wish to improve the wear (erosion) resistance of the fire-side surface of a boiler tube exposed to flue-gas laden with fly-ash. Fly-ash deposits which form on this tube are periodically removed by a sootblower. Also assume that the tube is located in the economizer at a flue gas inlet within the reach of a sootblower, at a coal-fired power plant. The tube is made of carbon steel. The tube exhibits flat spots where the tube metal is lost during operation at a higher rate than other areas in the tube.

First, the SURFWEAR expert system requests information on the required task. The user is asked to choose from the two tasks shown in the first screen.

Screen No 1

The required task is

1. surface design for wear resistance
2. failure analysis and recommendations

Enter number(s) of appropriate value(s), WHY for information on the rule being applied or <H> for help.

The user knows that the task is surface design and enters 1 and presses ENTER.

Then the system requests information on the anticipated operating environment, as seen on the second screen.

Screen No 2

In the operating environment the components surface will

1. be exposed to hard particles or protuberances forced against and moving along it
2. be subjected to fluids (liquid or gas, the liquid may contain solids)
3. be in relative motion with conforming surfaces
4. be subjected to repetitive compressive stresses
5. not have any of the above characteristics
6. select 6 for a better description

Enter number(s) of appropriate value(s), WHY for information on the rule being applied or <H> for help.

The user can easily establish that the pipes will be subjected to fluids (flue-gas and/or steam containing fly-ash) and enters 2 and presses ENTER.

The system automatically determines what to ask next to determine the wear mode. In this case information regarding the specific environment is required.

Screen No 3

In the operating environment the component's surface will

1. be subjected to a continuing succession of impacts from solid particles [example: sandblast equipment]

2. be subjected to a striking action from a fluid (not containing particles) [examples: pipe elbow, rain on aircraft]

3. move relative to a liquid in a region of collapsing vapour bubbles which cause local high impact pressures or temperatures [examples: pumps, mixing impellers, ultrasonic devices]

4. have a mixture of solid particles in a liquid (slurry) in motion with respect to it [examples: oil drilling, pumping, mineral benefication]

5. not be subjected to any of the above conditions

Enter number(s) if appropriate value(s), WHY for information on the rule being applied or <H> for help.

Since there is a continuing succession of impacts from fly-ash, the user enters 1 and presses ENTER.

Based on the provided information, the system performs a diagnosis and determines the wear mode. A detailed description is displayed. The user is then given a list to select a material out of which the item (substrate) under consideration is made from (screen No. 4).

Screen No 4

The substrate is made of

1. aluminium alloy
2. copper alloy
3. carbon steel
4. alloy steel (hardenable)
5. cast iron
6. martensitic stainless steel
7. austenitic stainless steel
8. magnesium alloy
9. nickel alloy
10. titanium alloy
11. zinc alloy
12. tool steel
13. other material

Enter number(s) if appropriate value(s), WHY for information on the rule being applied or <H> for help.

Knowing that the tube is made of carbon steel, 3 is entered and ENTER is pressed.

Now a list of applicable processes appears in the fifth screen.

Screen No 5

Any of the following methods to improve wear resistance are recommended:

1. fusion hardfacing with high carbon iron/chromium alloys
2. thermal spraying with ceramics (only for fine particles, 50 μm and low-angle incidence)
3. adding carbide wear tiles
4. adding ceramic wear tiles

Enter number(s) if appropriate value(s), WHY for information on the rule being applied or <H> for help.

In the case of economizer tube erosion problem, the user will choose 1 or 2 as applicable surface treatment processes. Methods 3 and 4 are not suitable for this purpose.

From this example we can see that some surface treatment processes are more suitable than others depending on the particular component (shape and size) and application. In general, the

user would consult the information in the text files which describe the various applicable surface treatment processes before a selection is made of the most applicable process. It should also be noted that the recommendations reached are not, in most cases, the only applicable processes. Due to the generic nature of this expert system it is not possible to include all known processes and applications. Thus it is suggested that SURFWEAR be customized to include methods and practices used at a particular location. These are often equipment and service environment specific.

After viewing this text, print options are available.

Screen No 6

To print, select from the choices below.

1. print the text which describes the wear mode
2. print the text describing the applicable process
3. print both
4. none of the above

Enter number(s) if appropriate value(s), WHY for information on the rule being applied or <H> for help.

Finally the explanation screen is displayed and a one-line summary of the process is presented.

At this point it is possible to take a look at the rule(s) used to arrive at this process. Simply enter 1 and ENTER, and a rule, like the one on screen No 7 will be displayed.

Screen No 7

RULE NUMBER: 236
IF:

(1) The wear mode is solid particle impingement
and (2) The substrate is made of low carbon steels or austenitic stainless steels or nickel alloys
and (3) Any of the following methods to improve wear resistance are recommended: thermal spraying with ceramics (only for fine particles, so μm and low-angle incidence)

THEN:

An applicable process is THERMAL SPRAYING WITH CERAMICS
- Probability = 10/10.

An applicable process is FUSION HARDFACING WITH HIGH CARBON IRON/CHROMIUM ALLOYS
- Probability = 10/10.

6. SUMMARY

A rule-based system, to assist designers and maintenance personnel who are involved in surface engineering, was developed. This micro-computer based software package is an essential tool for efficient analysis of wear modes and recommendation of surface improvement methods. However, due to the generic nature of this expert system it is not possible to include all known processes and applications. Thus it is suggested that SURFWEAR be customized to include methods and practices used at a particular location. These are often equipment and service environment specific.

Recommended by:

R.G. Fleck
Supervising Engineer
Materials Technology Section
Metallurgical Research Department

Approved by:

J. Brown
Manger
Metallurgical Research Department

Prepared by:

P. Mayer
Senior Metallurgist
Materials Technology Section
Metallurgical Research Department

for P. Mayer
D. LeFrancois

Summer Student
Materials Technology Section
Metallurgical Research Department

7. REFERENCES

[1] EXSYS is an Expert System Development Package, available from EXSYS Inc. PO Box 75158, Contr. 14 Albuquerque, NM 87194, USA.

[2] Surface Engineering For Wear Resistance, Kenneth G. Budinsky, 1988, Prentice-Hall, Englewood Cliffs, New Jersey.